(12) UK Patent Application (19) GB (11) 2 335 099 (13) A

(43) Date of A Publication 08.09.1999

(21) Application No 9904179.0

(22) Date of Filing 24.02.1999

(30) Priority Data
(31) 9803699 (32) 24.02.1998 (33) GB
(31) 9814713 (32) 08.07.1998

(51) INT CL[6]
H03D 7/00, H01Q 3/26

(52) UK CL (Edition Q)
H3R RMX
H1Q QFH
U1S S2139

(56) Documents Cited
US 5113094 A US 4723113 A US 3983489 A

(58) Field of Search
UK CL (Edition Q) H3R RMX
INT CL[6] H01Q, H03D
Online: WPI, JAPIO, EPODOC

(71) Applicant(s)
The Queens University of Belfast
(Incorporated in the United Kingdom)
8 Malone Road, BELFAST, BT9 5BN, United Kingdom

(72) Inventor(s)
Vincent F Fusco
Shyam L Karode

(74) Agent and/or Address for Service
Murgitroyd & Company
373 Scotland Street, GLASGOW, G5 8QA,
United Kingdom

(54) Abstract Title
Phase conjugate mixer circuits and retroreceive antenna

(57) A circuit for deriving a signal which is a phase conjugate of an input signal comprises a harmonic mixer including a combiner 60 and an antiparallel diode pair 62, 64 and a filter 66 wherein the local oscillator signal is at the same frequency as the input signal but is substantially stronger than the input signal. A retroreceive antenna system (fig.2 not shown) utilising the inventive mixer comprises two antenna elements equispaced about the antenna centreline. The signal received at a first element is mixed with a signal from the local oscillator and combined with received signal from the other antenna to provide an output signal containing phase conjugate information for use as a control in steering the antenna.

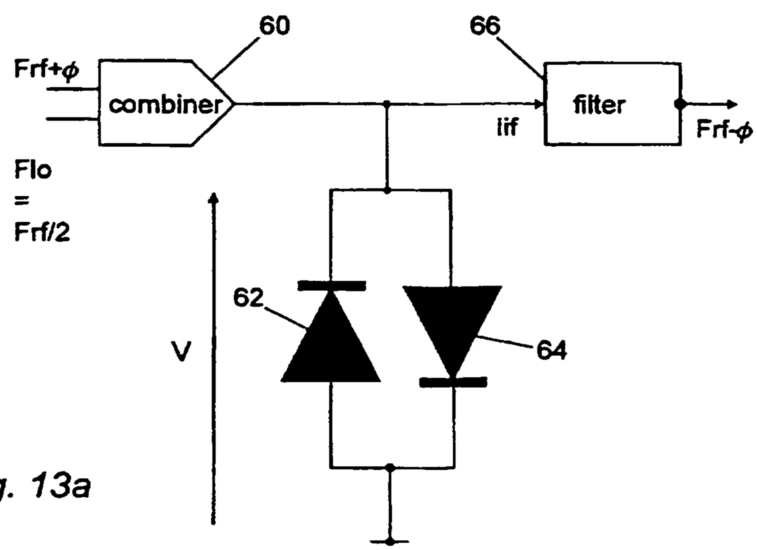


Fig. 13a

GB 2 335 099 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 1995

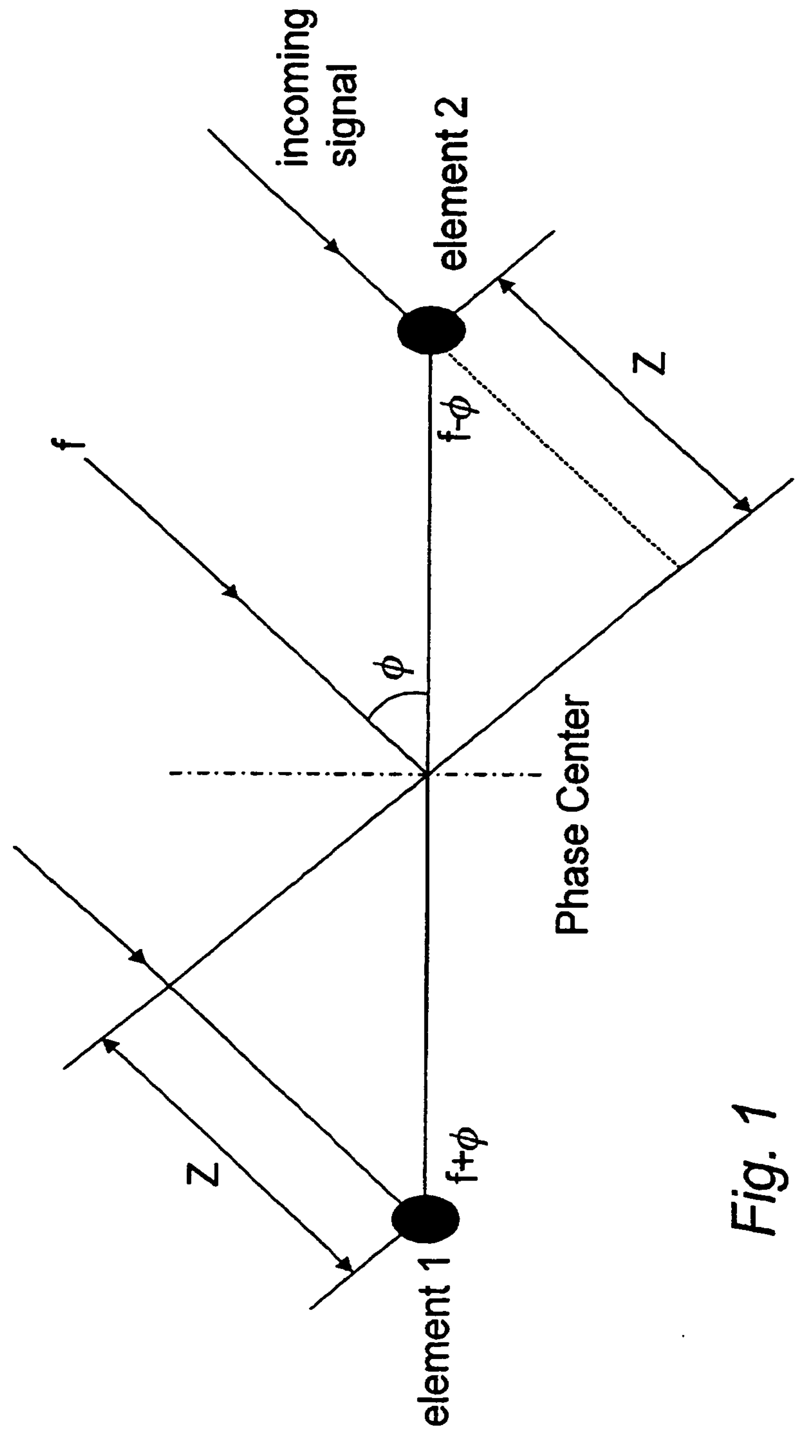

incoming signal
element 2
f
Z
f-ϕ
ϕ
Phase Center
Z
f+ϕ
element 1

Fig. 1

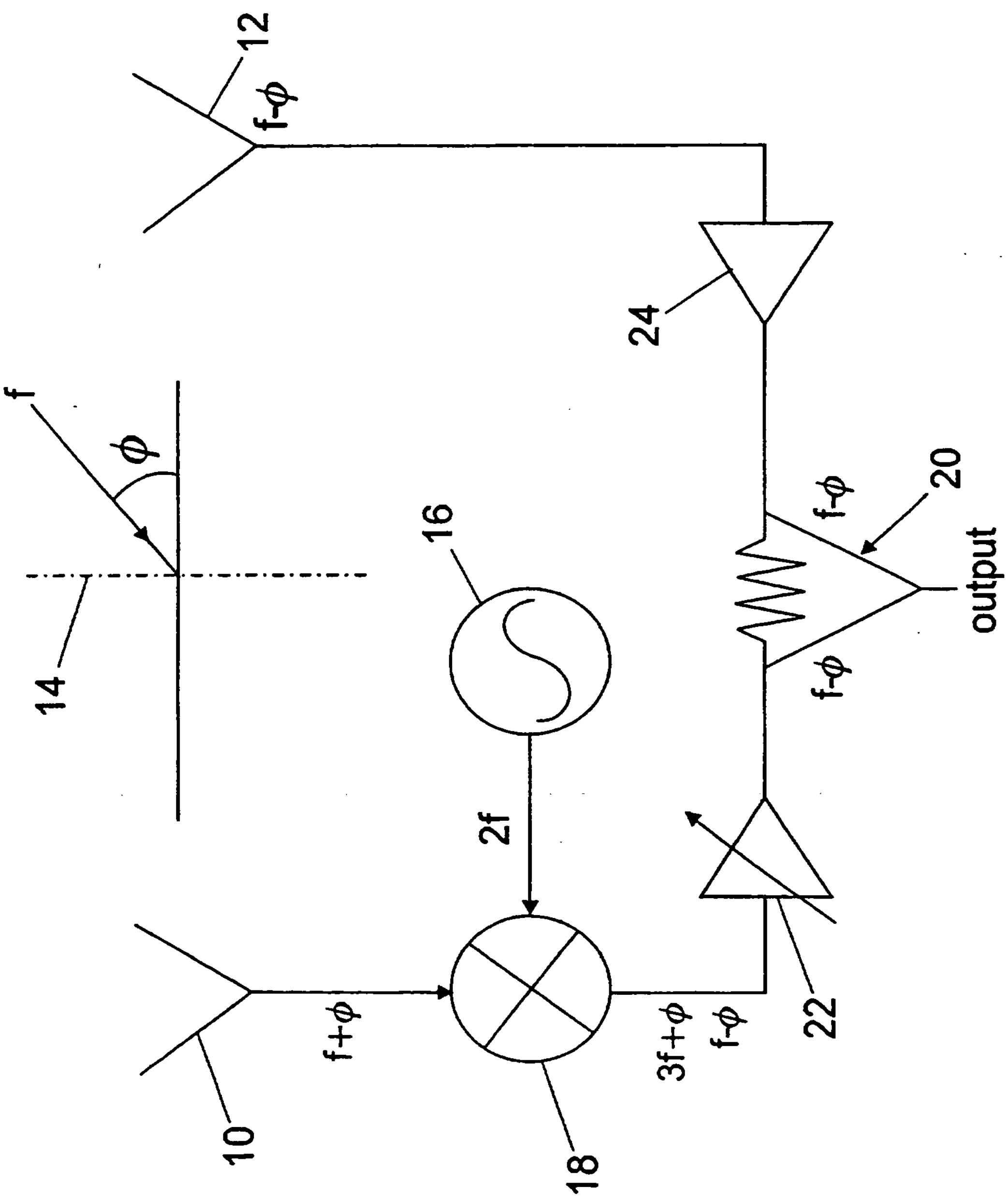

f
ϕ
14
12
f-ϕ
24
16
2f
20
f-ϕ
f-ϕ
output
10
f+ϕ
18
3f+ϕ
f-ϕ
22

Fig. 2

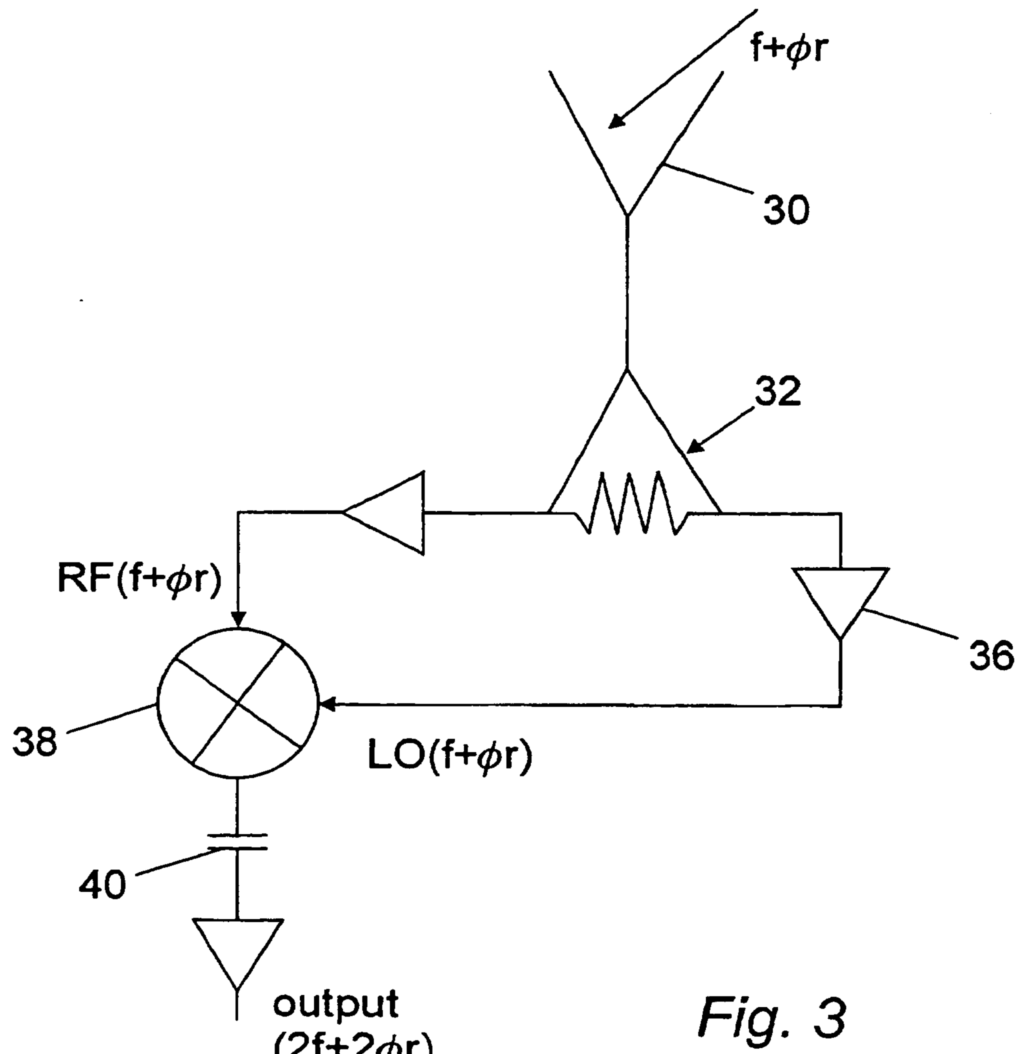


Fig. 3

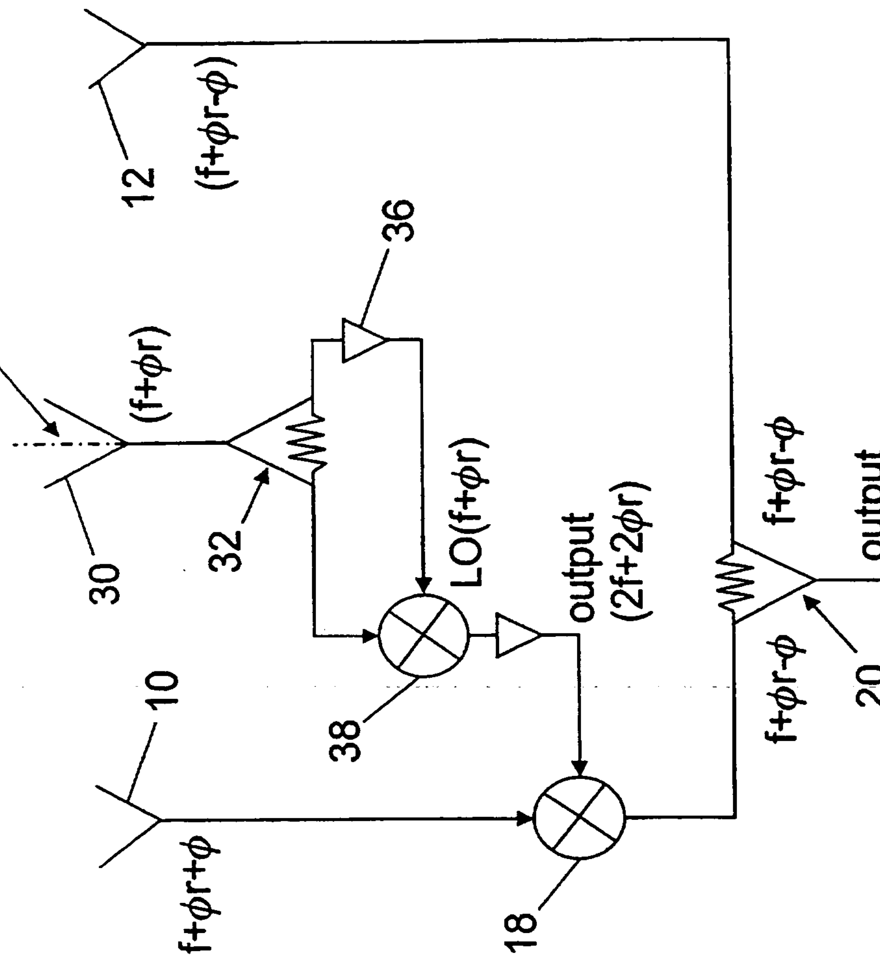

f
(f+φr)
30
32
36
LO(f+φr)
output
(2f+2φr)
38
10
f+φr+φ
18
12
(f+φr-φ)
f+φr-φ
f+φr-φ
output
20

Fig. 4

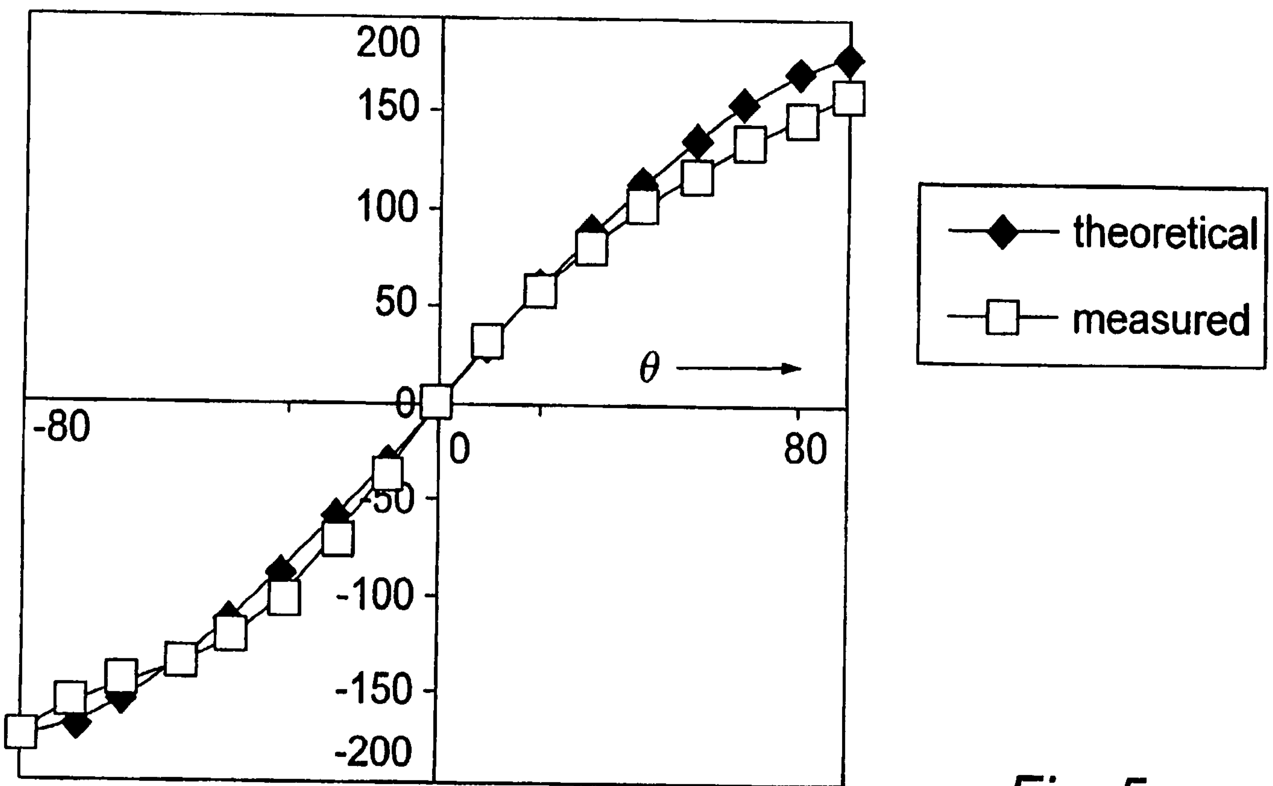

200
150
100
50
0
-50
-100
-150
-200
-80
0
80
θ
theoretical
measured

Fig. 5

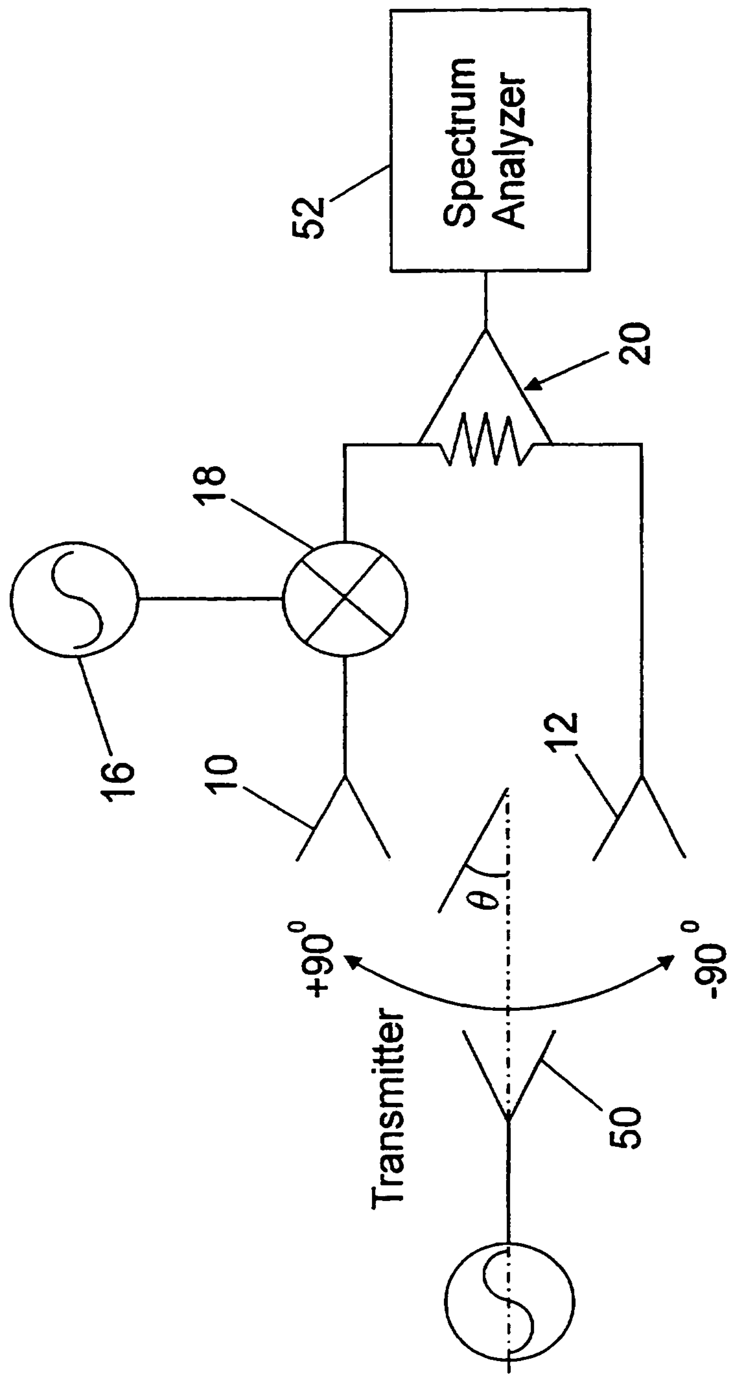


Fig. 6

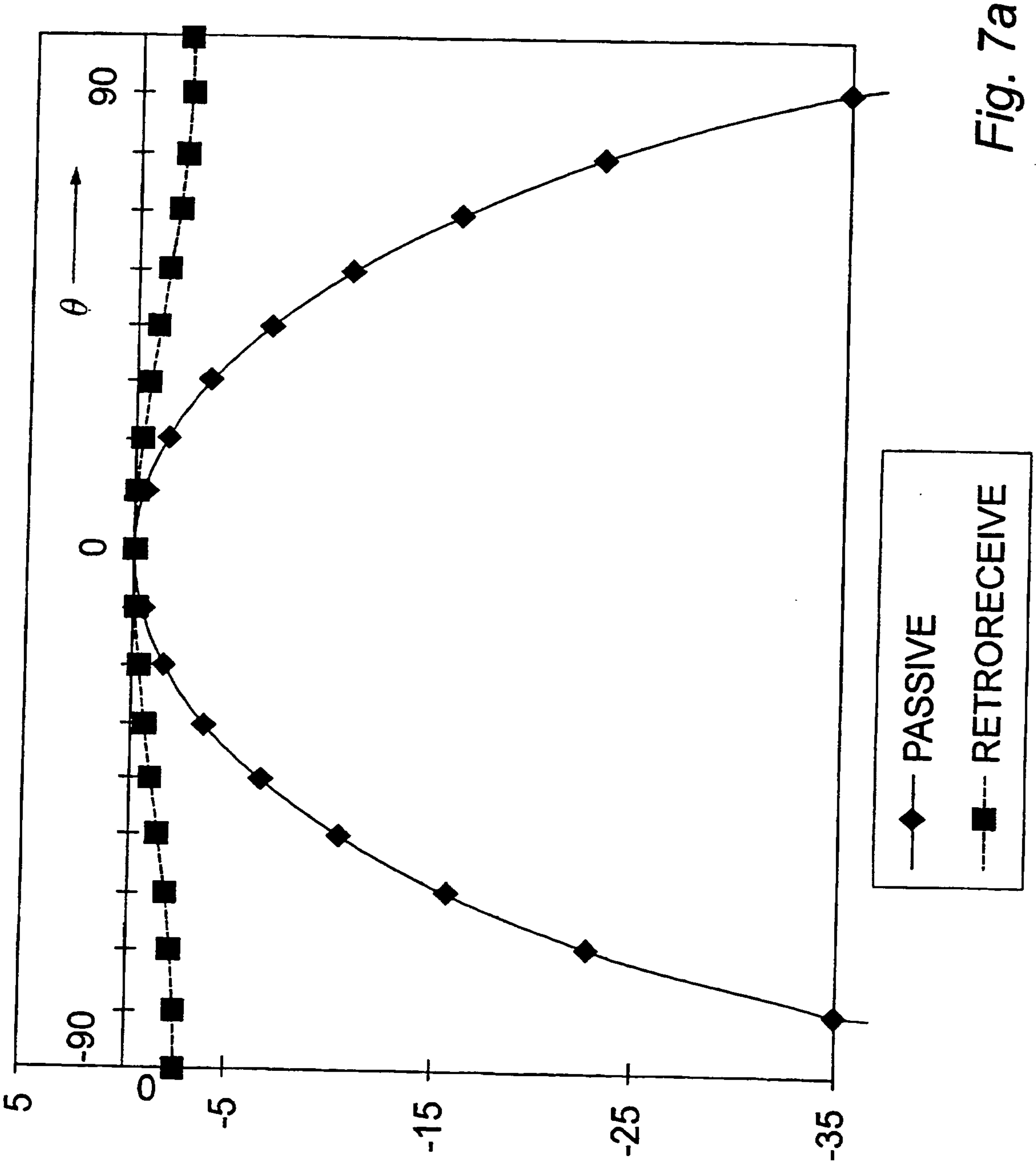


Fig. 7a

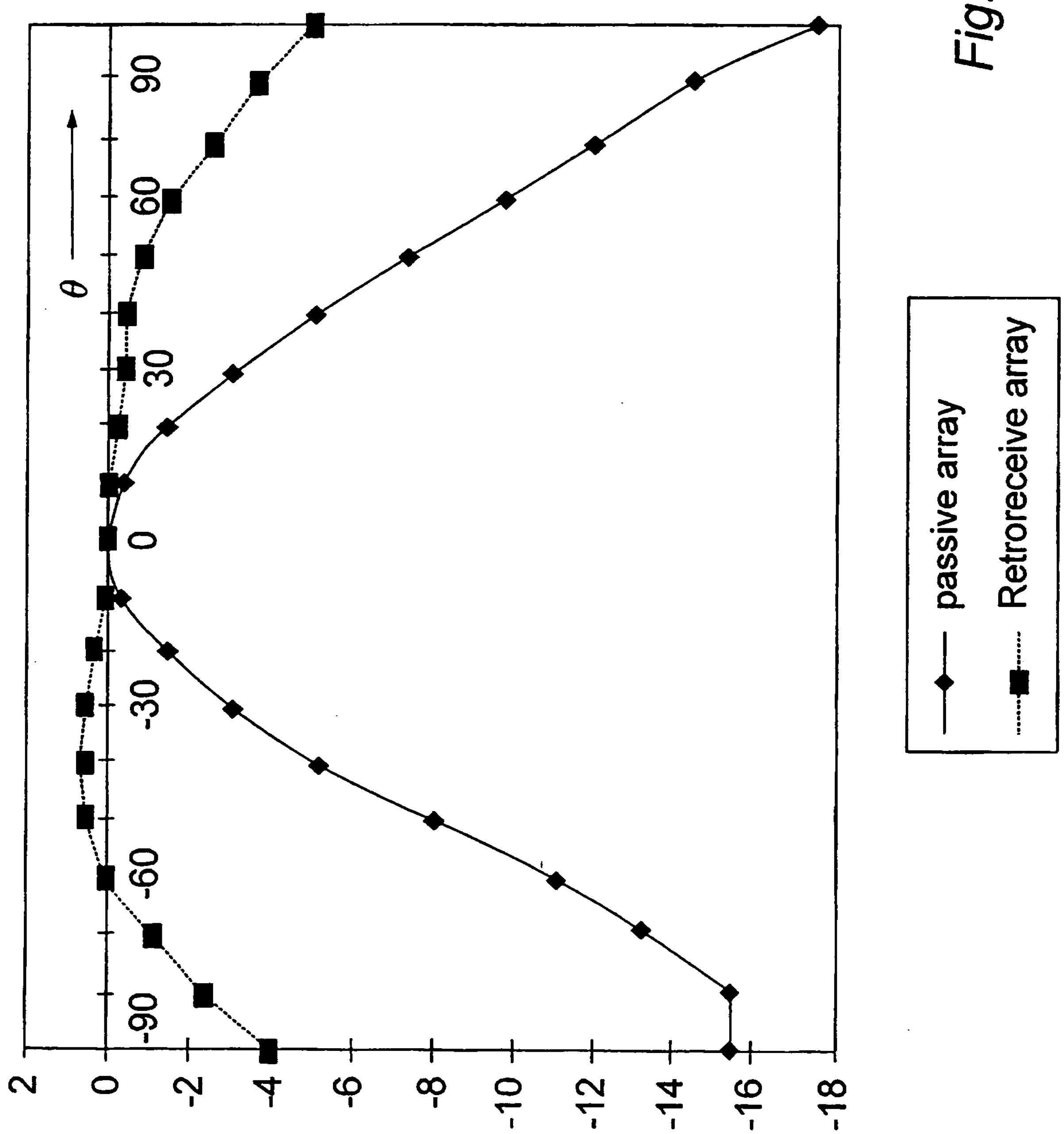

θ
-90
-60
-30
0
30
60
90
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
passive array
Retroreceive array

Fig. 7b

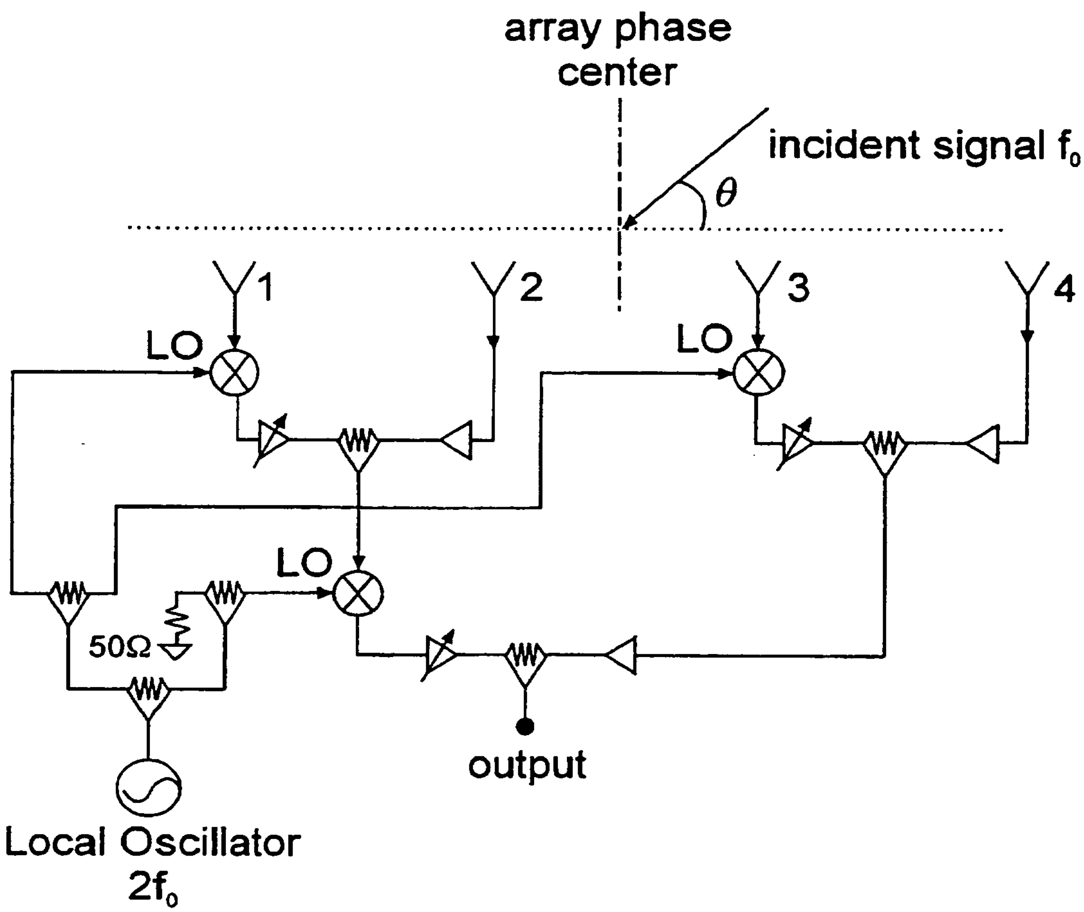

array phase center
incident signal f_0
θ
1
2
3
4
LO
LO
LO
50Ω
output
Local Oscillator
$2f_0$

Fig. 8

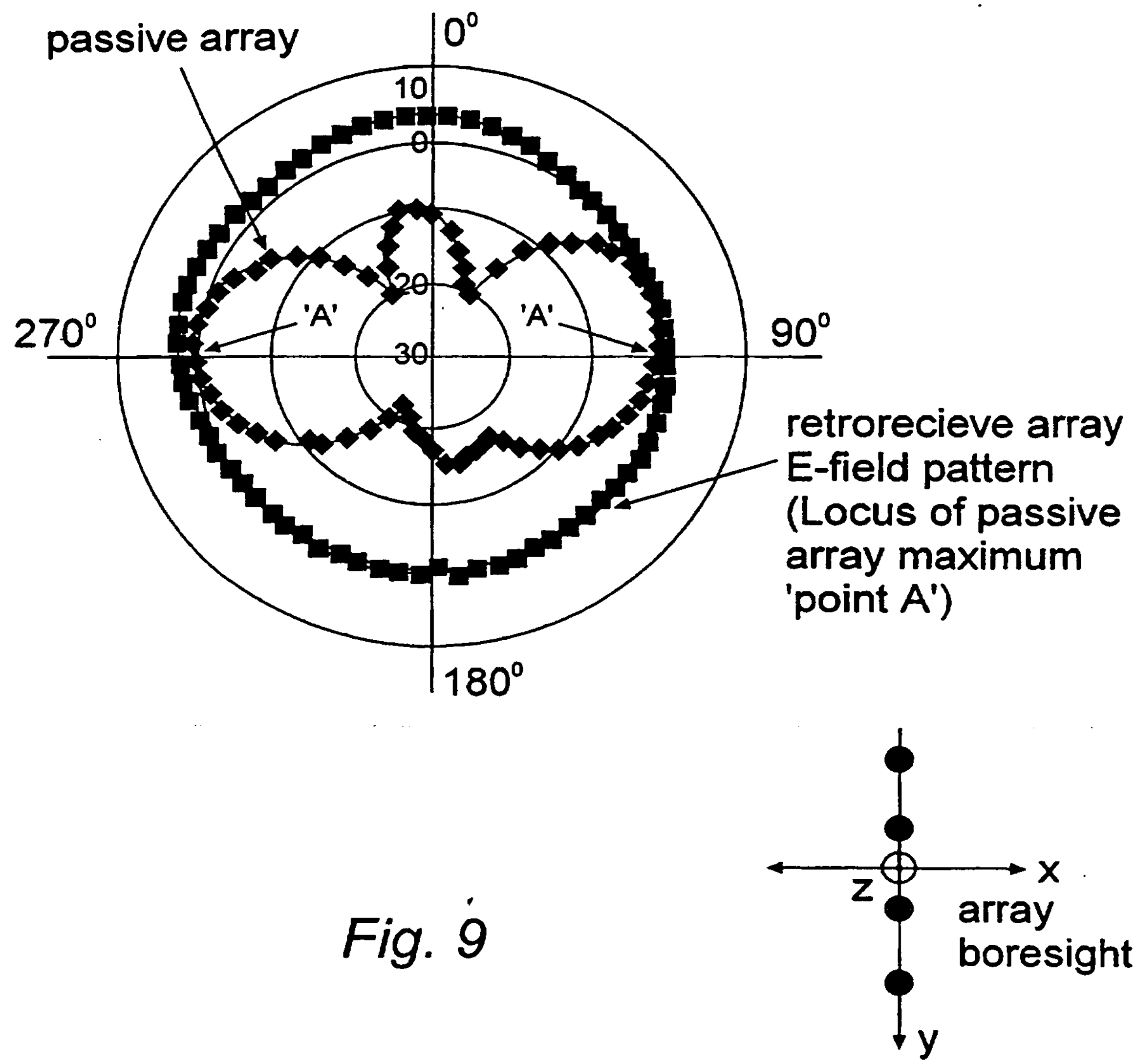

passive array
0°
10
0
20
30
270°
90°
'A'
'A'
retrorecieve array
E-field pattern
(Locus of passive
array maximum
'point A')
180°
x
z
array
boresight
y

Fig. 9

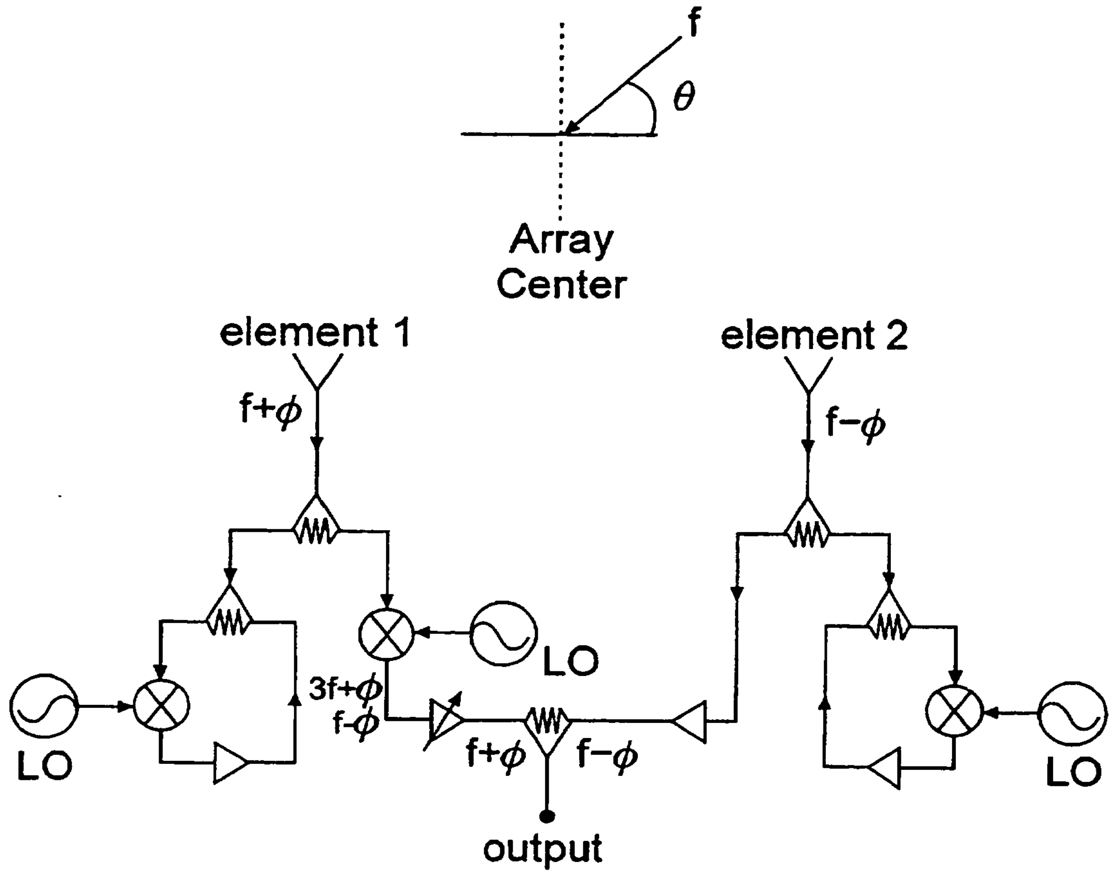
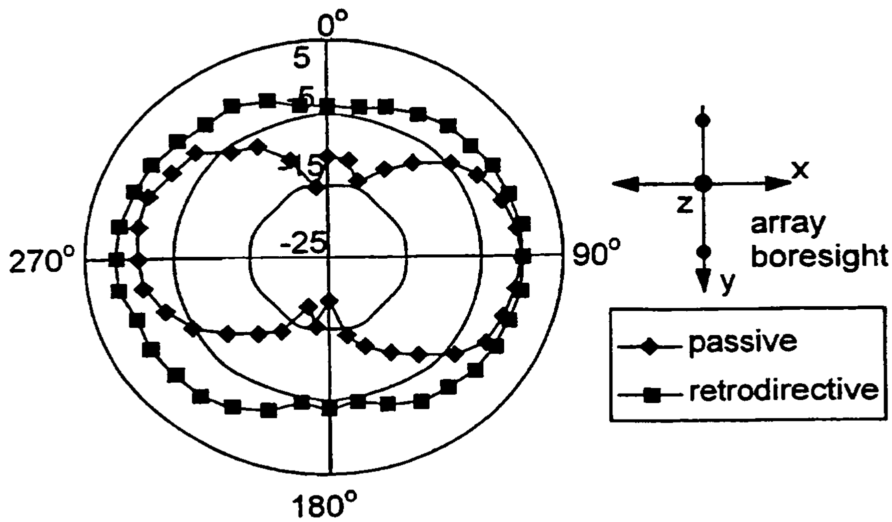
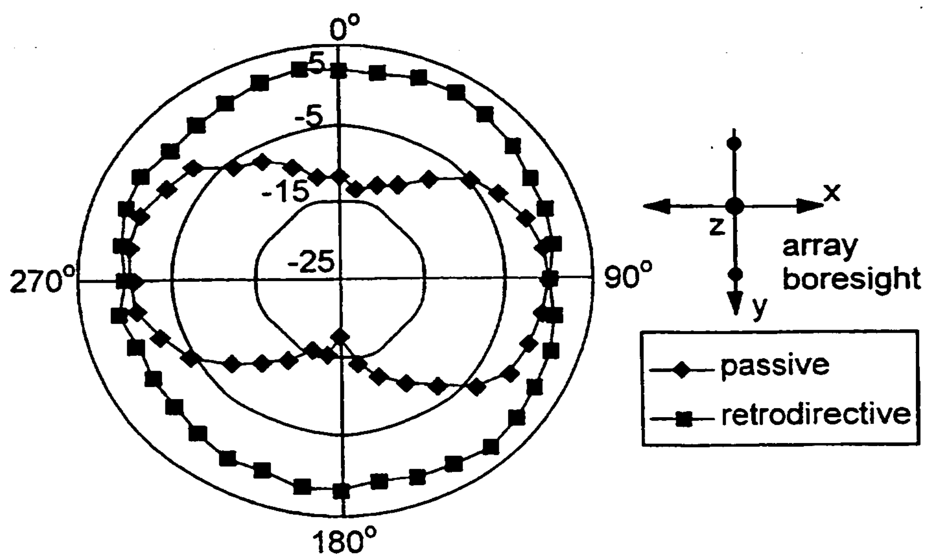

f
θ
Array
Center
element 1
element 2
f+ϕ
f−ϕ
LO
LO
LO
3f+ϕ
f-ϕ
f+ϕ
f−ϕ
output

Fig. 10



0°
5
-5
-15
-25
270°
90°
180°
x
z
y
array
boresight
passive
retrodirective

Fig. 11



0°
5
-5
-15
-25
270°
90°
180°
x
z
y
array
boresight
passive
retrodirective

Fig. 12

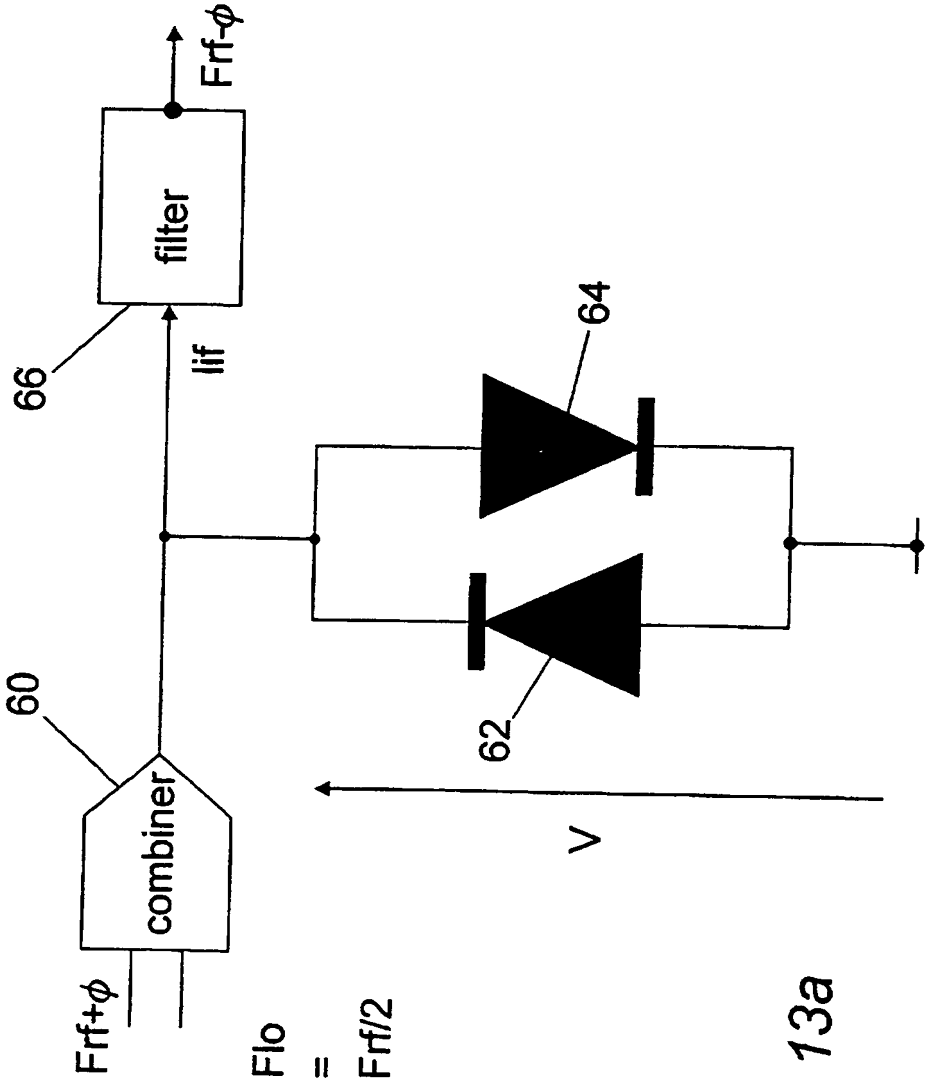


Fig. 13a

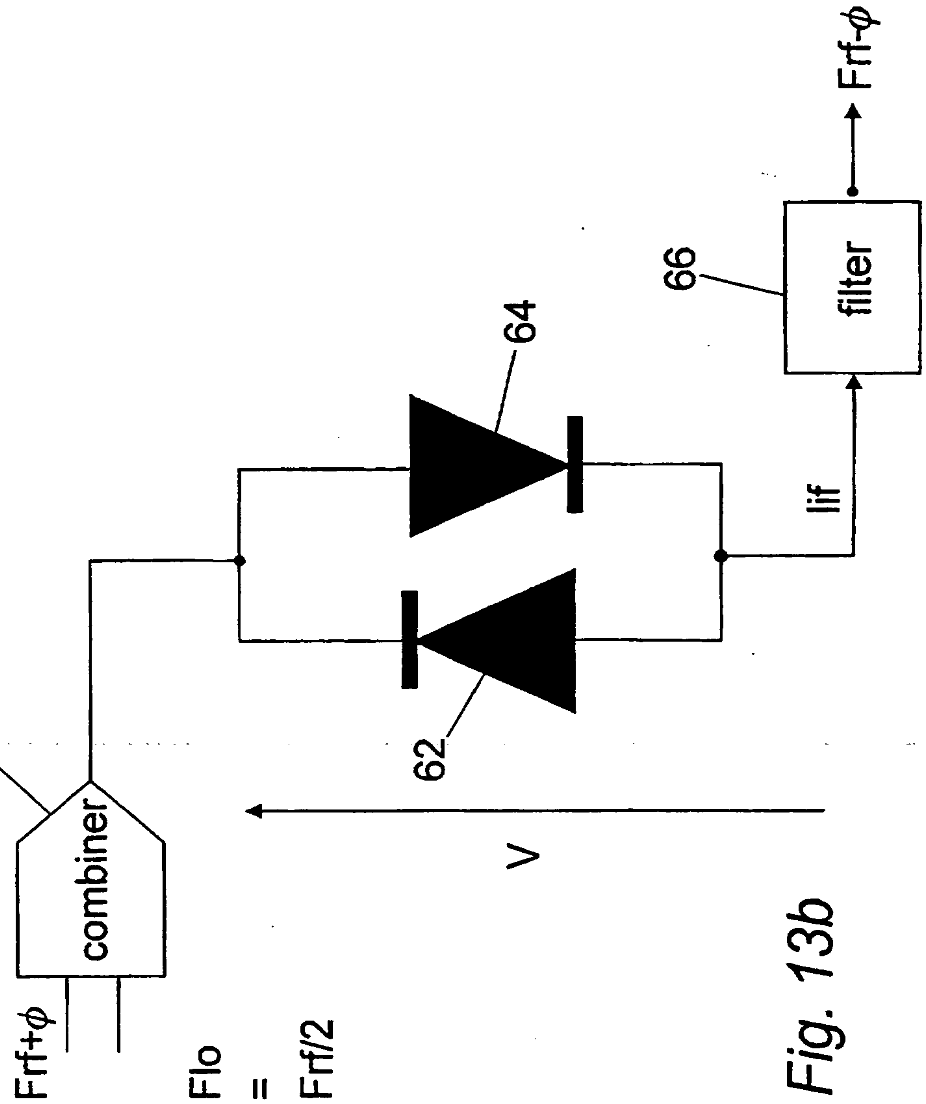


Fig. 13b

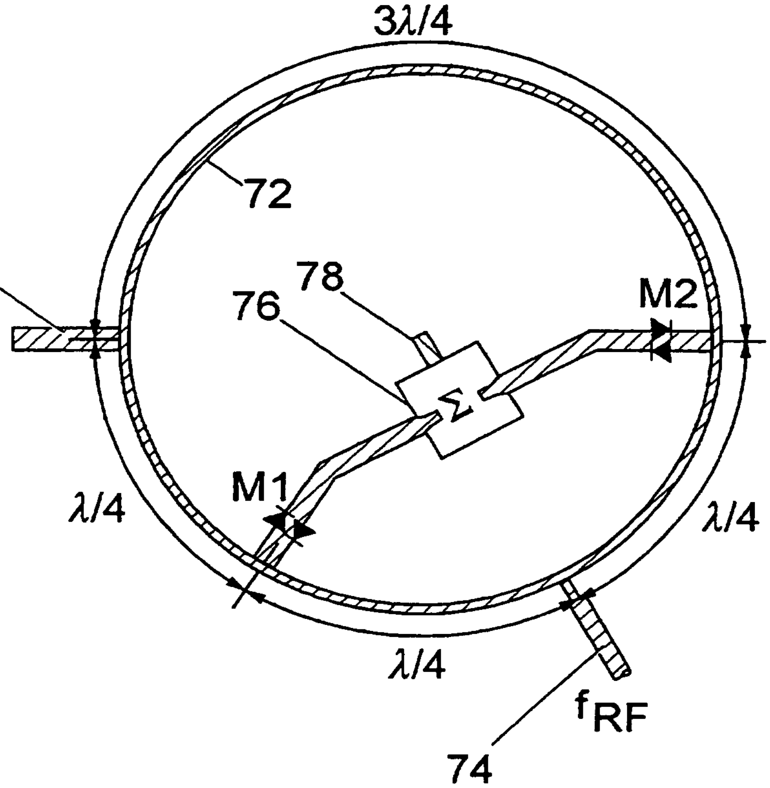


Fig. 14

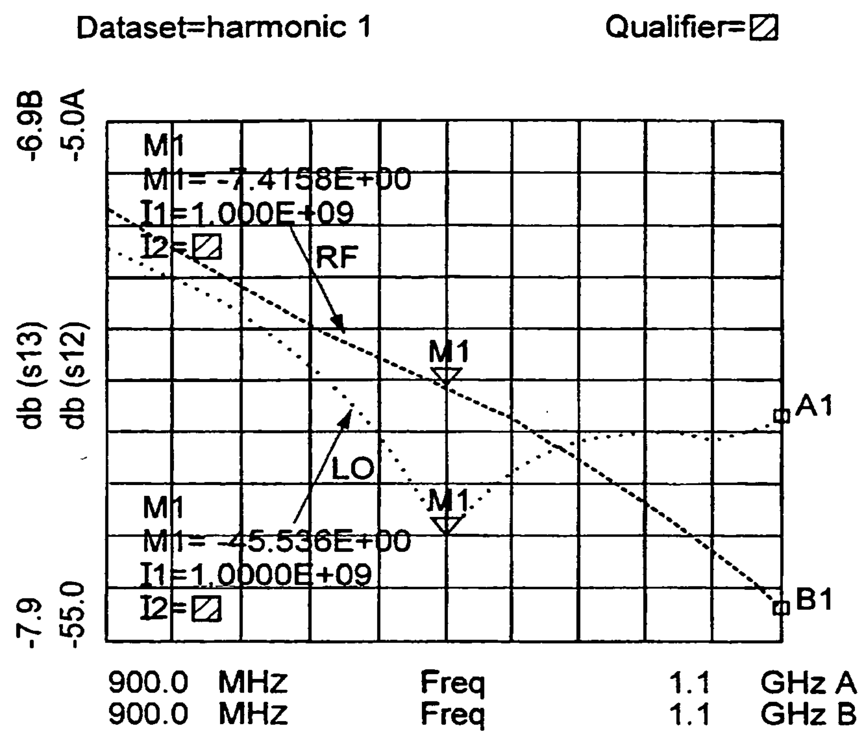

Dataset=harmonic 1
Qualifier=
-6.9B
-5.0A
db (s13)
db (s12)
-7.9
-55.0
M1
M1= -7.4158E+00
I1=1.000E+09
I2=
RF
M1
A1
LO
M1
M1
M1= -45.536E+00
I1=1.0000E+09
I2=
B1
900.0 MHz Freq 1.1 GHz A
900.0 MHz Freq 1.1 GHz B

Fig. 15

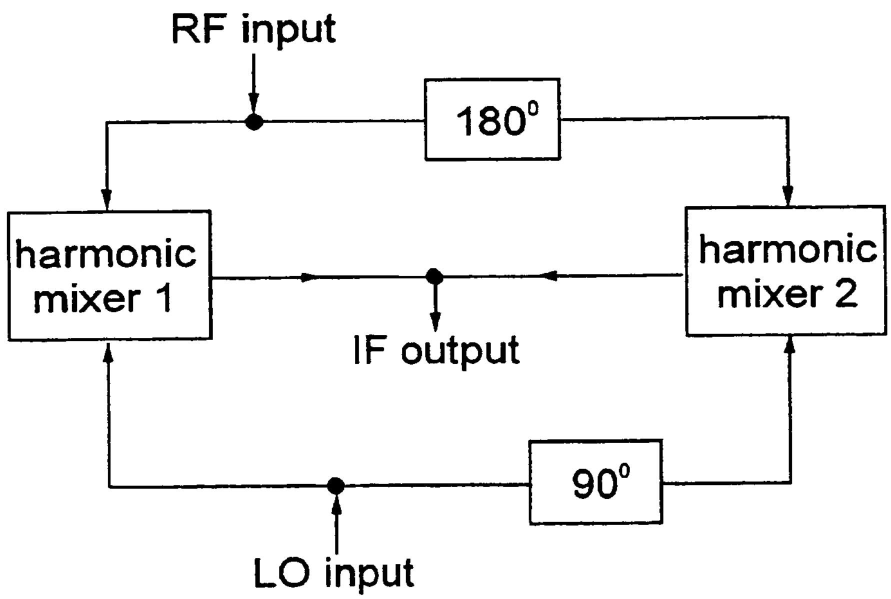

RF input
180°
harmonic mixer 1
harmonic mixer 2
IF output
90°
LO input

Fig. 16

PHASE CONJUGATE CIRCUIT AND RETRORECEIVE ANTENNA

This invention relates to phase conjugate circuits. One field of application of such circuits is in retroreceive antennas, but the invention may be used in other applications. The invention also relates to retroreceive antennas as such.

It is known that a conventional mixer when operated with a local oscillator signal running at twice the frequency of an incoming signal will cause an input signal to be phase conjugated. See for example Pon, C.Y., IEEE Trans on Antennas and Propagation, vol. AP-12, pp. 176-180, March, 1964.

The disadvantage of this mixer approach of achieving phase conjugation is that an oscillator at twice the frequency of the incoming wavefront is required. This can be very disadvantageous particularly when very high frequency operation such as at millimetre frequencies is required e.g. for anti-collision CW radars at 77 GHz (here a 154 GHz oscillator would be required). Such an oscillator would be very difficult to construct using technology available today.

This invention, in one aspect, relates to the use of a harmonic mixer as a phase conjugate circuit which does not require the use of a local oscillator circuit at twice the frequency of the incoming signal.

The present invention provides a method of deriving phase conjugate information from an input signal of a given frequency, the method comprising mixing the incoming signal in a harmonic mixer with a local oscillator signal, and in which the local oscillator signal is of said given frequency and is substantially stronger than said input signal.

The invention also provides a circuit arrangement for deriving phase conjugate information from an input signal of a given frequency, comprising a harmonic mixer having a first input receiving said input signal and a second input for connection to a local oscillator, the circuit arrangement further comprising a local oscillator operating at said frequency and connected to supply said second input with a signal which is substantially stronger than said input signal.

From another aspect, this invention relates to a new type of receive antenna architecture suitable for various communication applications. The new antenna array is capable of steering its beam towards the source without prior knowledge of its position and without the need for supplementary reference signals generated to the array. By doing so it combines the advantages of an omnidirectional antenna (maximum response in all receive directions) with that of a directive antenna i.e. narrow beam and high gain in the desired direction.

By way of background, incident signals received by an

antenna array at angles other than boresight introduce phase shifts in the signals received at each element due to the time difference in the signals arriving at each element; this is shown in Figure 1.

The phase shift depends on the angle of incidence of the incoming signal with respect to the receive array axis. In order to steer the receive beam in the direction of the incoming signal it is necessary to adjust the phases of the signal received at each element before summing them in such a way that they add in phase. Automatic beam steering requires automatic phase adjustment at each element. In principle methods reported earlier for achieving this effect include the use of external phase shifters, or a pilot carrier to establish the correct phase relationship of the incoming signal component for in phase beam formation; see M.J. Withers et al, "Self-Focusing Receiving Array", Proc. IEE, Vol. 112, No 9, September 1965, pp 1683-1688.

The present invention provides a retroreceive antenna system comprising an antenna array having two elements spaced apart, means for deriving from the signals received at the two elements the phase relationship between said received signals, and means for steering the antenna array to minimise the phase difference; and in which said means for deriving the phase relationship comprises a mixer.

In the new method presented here the known phase conjugation properties of a mixer output signal components are used to establish the phases of the signals received at each element so that they always add in phase for all possible angles of arrival of the signal. The principle of using a mixer for phase

conjugation purposes has previously been utilised in a retrodirective antenna array where only a self steered transmit function was achieved; See Pon C.Y., "Retrodirective Array Using the Heterodyne Technique", IEEE Trans on Antenna and Propagation, March 1964, pp 176-180. In the new architecture presented in this work a method is given which permits automatic signal reception from any arrival direction. This facility has not previously been reported based on the mixer self-conjugation properties. As a consequence the new array does not need a pilot tone or phase shifters for its operation.

Embodiments of the invention will now be described, by way of example only, referring to the drawings, in which:

Fig. 1 illustrates phase shift in received signals, as discussed above;

Fig. 2 is a block diagram of a two element embodiment of a retroreceive antenna in accordance with the invention;

Fig. 3 is a block diagram of a reference signal generator which may optionally be used in carrying out the invention;

Fig. 4 illustrates an embodiment of retroreceive antenna using the reference signal generator of Fig. 3;

Fig. 5 is a graph of theoretical and measured phase difference at different angular positions;

Fig. 6 illustrates a radiation pattern measurement

set-up used for experimental confirmation of the invention;

Figs. 7a and 7b are respectively theoretical and measured radiation patterns for two-element passive and retroreceive arrays;

Fig. 8 illustrates another embodiment of retroreceive array;

Fig. 9 is a plot of the performance of the array of Fig. 8 compared with that of a passive array;

Fig. 10 illustrates a two-element retrodirective transceiver array incorporating a retroreceive system embodying the invention;

Fig. 11 is a plot, similar to that of Fig. 9, showing the receiver performance of the array of Fig. 10;

Fig. 12 is a similar plot for the retransmit performance;

Figs. 13a and 13b are alternative forms of embodiments of a phase conjugation circuit;

Fig. 14 is a schematic illustration of a more detailed embodiment of phase conjugation circuit following the principles of Fig. 13;

Fig. 15 is a graph of simulated isolation properties of the embodiment of Fig. 15; and

Fig. 16 is a block diagram of a further refinement of the embodiment of Fig. 14.

The operation of the embodiment of Fig. 2 will now be described. When the incident signal arrives at any angle other than boresight, a phase delay is introduced into the signal received at each element 10, 12 comprising the array. If both the elements 10 and 12 are at equidistance from the array centre 14 the signals received by these elements 10, 12 will have equal but opposite phases, ie these signals bear a phase conjugation relationship with respect to each other,

Let the signals received by element 1 and 2 be

$e^{j(\omega t-\phi)}$ and $e^{j(\omega t+\phi)}$ respectively (1)

The signal from one of the elements 10 is mixed in a mixer 18 with a reference signal from a local oscillator 16 at twice the frequency of the incoming signal. The basic output of the mixer 18 will have two products, one of which (the difference product) has the same frequency as that of input to the mixer but with conjugate phase.

At output of the mixer 18, the sum product is

$-e^{j(2\omega t+\omega t+\phi)}$ or $e^{j(3\omega t+\phi)}$ (2)

and the difference product is

$-ej(2\omega t-(\omega t+\phi))$ or $e^{j(\omega t-\phi)}$ (3)

The $e^{j(\omega t+\phi)}$ output of the mixer 18 and the signal from the other element 12 can be added together using a power combiner 20 to give an in-phase power combined response for any angle of arrival of the incoming

signal in the azimuthal plane. The sum product at three times the frequency of the incident signal can be easily filtered leaving only the difference product to be added to the signal received from element 10. As these signals always remain in phase at all angles of incidence, the beam is automatically steered towards the source without prior knowledge of its position. The insertion of the mixer 18 may introduce imbalance in the power level of the signal reaching the power combiner 20. This problem can be overcome by using amplifiers 22, 24 and by making sure that the amplitude of the input and the output signals at the mixers are maintained equal.

In a situation where the local oscillator has a relative phase shift with respect to the signal then it is shown that the array again gives retroreceive response at all the azimuthal positions. Let the relative phase error of the free running local oscillator be α_t.

When the incident signal is at an angle $\phi 1$ then let the signals at the two elements be

$\omega t + \phi 1$ and $\omega t - \phi 1$ (4)

Before summation the signals will be

$\omega t + \alpha - \phi 1$ and $\omega t - \phi 1$ (5)

When the incident signal comes from a new angle $\theta 2$ then let the signals at two elements be-

$\omega t + \phi 2$ and $\omega t - \phi 2$ (6)

Before summation the signals will be

$\omega t + \alpha - \phi\ 2$ and $\omega t - \phi 2$ (7)

The phase changes occurred at these elements while shifting the angle of incident signal from ϕ to $\phi 2$ can be obtained by taking the difference of phases at these elements at positions $\phi 1$ and $\phi 2$ - ie subtracting

equation 5 and 7, thus the phase change at element 1-

$$(\omega t + \alpha - \phi 1) - (\omega t + \alpha - \phi 2) = \phi 2 - \phi 1 \quad (8)$$

thus

$$(\omega t - \phi 1) - (\omega t - \phi 2) = \phi 2 - \phi 1 \quad (9)$$

Equation (8) and (9) show that phases of the received signals at elements 10 and 12 remains the same even when the angle of arrival of the incident signal is changed, thus maintaining the desired constant output response for all the azimuthal positions, i.e. retroreceive operation even when the local oscillator signal is not phase locked to the incoming signal. Thus the need to generate local oscillator signal from the incoming wavefront is not a requirement.

Reference is now made to Figure 3. Although not absolutely necessary, the reference signal used as a local oscillator signal for the mixer can be generated by the signal received from a reference antenna 30 placed at the array centre. This signal can be used as shown here for the primary mixing purpose, the provision of absolute phase information, or other information extraction purposes such as locking up a phase locked loop for a secondary application. The reference signal generator circuit is shown in Figure 3.

Here the signal received by the reference antenna 30 is divided using a power divider 32 and suitably amplified at 34 and 36. These two signals are then mixed together using a mixer 38. As both RF and the LO signals are the same frequency, the difference product from the mixer will consist of a DC offset cos (ϕr) component blocked by a capacitor 40 and the sum product which has twice this frequency: effectively the mixer acts as a frequency doubler. This signal contains the

necessary phase reference information for proper operation of the array and could be used as the LO signal for the mixer at different elements.

The complete circuit architecture for the two element retroreceive antenna with the optional reference generator circuit included is shown in Figure 4.

To verify the concept, initially measurements were carried out on the basic retroreceive antenna shown in Figure 1. A passive two element array was also tested in order to provide a performance comparison and a proof of concept. In both these arrays microstrip patch antennas were used as elements.

A microwave phase bridge 52 (Fig. 6) was used to measure the phase difference between the signals received at each element for a simple two element receive array without the retroreceive property included. Here $\omega t+\phi$ from element 10 is measured relative to that at element 2 (taken as the reference channel for the phase bridge) ωt giving a measure of the angle of arrival $\cos(\phi)$. Figure 5 shows theoretical and measured data.

In order to compare retroreceive performance the experimental set-up shown in Figure 6 was used for the radiation pattern measurement. Since we have a 2X1 test array only the azimuthal plane response ws measured. Here the position of a transmitter antenna 50 in the retroreceive array far field was kept at a fixed radial distance from the receiver antenna 10, 12 and moved to different angular positions in the azimuthal plane. Radiation pattern measurement was also carried out on a 2X1 passive array for comparison. Theoretical patterns for the retroreceive array and the

passive array are shown in Figure 7a and the measured data is shown in Figure 7b.

From Figure 7a when compared to the radiation pattern of the passive array the radiation pattern of the retroreceive antenna is much flatter in the azimuthal plane. This indicates that for each angular position θ of the transmitter antenna the boresight of the radiation pattern formed by the retroreceive antenna was always pointing to within ±3.0dB towards the transmitter. The fall in the power received by the array at positions far from boresight ($-90° \le \phi \le +90°$) is due to the far field radiation pattern of the microstrip patch antenna used as array elements. theoretically the array factor is constant at all angular positions in the azimuthal plane thus if omnidirectional elements are used then such an array can be used to steer the beam anywhere over the entire 0-360° azimuthal positions.

A further experimental antenna is now described. To show the potential of the retroreceive system a 4X1 retroreceive antenna was fabricated using $\lambda/4$ monopole antennas over quarter wave ground planes; these were used so as to allow a check on the performance of the array in entire azimuthal plane ie from 0° to 360° to be performed.

The circuit diagram of the 4X1 retroreceive array is shown in Figure 8. The measured radiation patterns are shown in Figure 9. The radiation patterns of the equivalent passive array are shown for comparison. The power received by the retroreceive array in the 0° to 360° range varies by less than 3dB indicating self steered receive coverage over the entire azimuthal plane. Here, as the transmitter moves in the azimuthal

plane, the receive beam of the retroreceive array automatically tracks the incident signal, aligning itself in that direction. This action results in uniform azimuthal coverage. The radiation pattern of the passive array results in a 3dB coverage of 54° in the front side (0-180°) and 49° in the back side (180°-360°)

Fig. 10 shows the use of the retroreceive configuration in a transceiver (ie self-steering/self-tracking) system. Such a system could be used in a next generation mobile communication applications. Such a transceiver array exhibits the capability of automatic steering of both transmit and receive polar patterns in the direction of the incoming signal. Here a conventional Pon architecture is used for the retrodirective transmit section while the retroreceive configuration which is the subject of this application, is used to form the self-steering receive section. Figure 11 shows the receive response of a two-element retrodirective transceiver array in receive mode, while Figure 12 shows the retransmit response. Here, monopole antennas are used as the radiating elements.

For reference in each case the radiation pattern of an equivalent two-element passive array is also included. Measured results for the example discussed here show that the passive array provides 3dB coverage of 65°in the front side and 65° in the front side and 60° in the back side on both transmit and receive modes. On the other hand, the retrodirective transceiver array is able to provide (to within a 3dB signal variation) coverage in the entire azimuthal plane from 0° to 360° in both transmit and receive modes.

This, we believe, is the first demonstration of a

transmit/receive unit which has self-steering capability on both transmit and on receive functions simultaneously.

Turning now to another aspect of the present invention, an improved form of harmonic mixer is described.

In its conventional mode of operation a harmonic mixer is driven with a LO at one-half of the frequency of the RF signal thereby reducing the complexity of the LO. If only even order harmonics are of interest (as they are for effective operation of the novel phase conjugate circuit required here), then the configuration shown conceptually in Fig. 13 is of interest. Here the FR and LO signals are applied to an antiparallel diode pair 62, 64 via a combiner/coupler 60. This arrangement presents reduced conversion loss compared to a fundamental mixer, and has low noise figure by virtue of suppression of LO noise side-bands. The novel step in this embodiment is not to drive the LO port of the harmonic mixer assembly at fRF/2 as in the conventional approach. Instead here we drive it at fRF. If we do this then mathematical analysis of the system shows that if the LO is much stronger than the RF an approximate expression for the current through the diode pair is derived as follows. With the LO peak voltage denoted by $V+V_{LO}\cos(\omega_1 t+\phi)$ the small signal conductance of each diode is

$$g_1=\alpha I_s\ e^{-\alpha V}$$

$$g_2 = \alpha I_s\ e^{\alpha V} \quad \text{where} \quad \alpha=e/kT\eta\ ,\ \eta \text{ being the}$$

ideality factory. The total conductance is

$$g = 2\alpha I_s\ [I_0(\alpha V_{LO})+2I_2(\alpha V_{LO})\cos 2\omega_L t+........]$$

where $I_{2k}(x)$ are modified Bessel functions of the argument x. The IF output current I_{IF} for an RF signal voltage V_{RF} cos $(\omega_s t+\phi)$ is

$$I_{IF}=2\alpha I_s I_2(\alpha V_L)\cos(2\omega_L t+2\theta-\omega_s t-\phi)$$

Thus phase conjugation is automatically obtained without recourse to a harmonic oscillator which otherwise is required by any other known mixer based technique. Here the $+\phi$ phase shift of the input RF signal has been phase conjugated to become $-\phi$.

The antiparallel diode pair may be connected in shunt with the combiner 60 and a filter 66 (Fig. 13A) or in series between them (Fig 13B).

Phase conjugation of a signal by using a mixer is a useful circuit function in its own right and as the key operating requirement of a retrodirective antenna array. The conventional approach uses a mixer to perform this task by using a local oscillator signal operating at twice the incident RF signal. A sub-harmonic mixer, on the other hand, uses a local oscillator signal at the same frequency as the RF signal. The reduces the complexity of the local oscillator source making it an attractive choice in high frequency retrodirective and retroreceive antenna array elements.

A practical physical embodiment of the principle using a 180° hybrid rat-race is now described. In principle other electronic configurations could be used to achieve the same result. A balanced version of the sub-harmonic mixer which provides LO isolation is described here (Figure 14). Here, the LO is applied to the DIFFERENCE port 70 of a 180° hybrid (rat race) 72, whereas the RF is applied to the SUM port 74. Two

pairs of diodes connected in back to back configuration are connected to the remaining arms of the hybrid shown as M1 and M2 in Figure 15. Due to the 180° relative phase shift in the LO signals applied to M1 and M2, the LO gets cancelled when the outputs from both the mixers are added together at 76. This provides high isolation for the LO signal at the output port 78. The harmonic mixing process described above allows a phase conjugate signal at the FR frequency to be generated as described in the theory section above. The difference product from mixers M1 and M2 bears the desired phase conjugate relationship with respect to the input RF signal and add in phase to provide maximum IF signal strength at the output port. Since the RF signal is supplied in-phase to two mixers, no cancellation occurs at the output and the input RF signal leaks to the output port resulting in poor isolation for the RF signal.

The LO and the FR leakage signals at the output port 78 of Figure 14 will be:

LO $(f_{LO}+90°) + (f_{LO}+270°)$
RF $(f_{RF}+\phi+90°) + (f_{RF}+\phi+90°)$

The RF leakage signals from M1 and M2, being in-phase, add at the output. The LO signal is cancelled since the LO signals from both mixers are 180° out-of-phase.

At a nominal operating frequency of 1GHz, simulated results in Figure 14 show that the LO isolation is -46dB whereas the RF-IF isolation is only -7.4 dB. The measured results indicate LO isolation of -29dB and RF isolation of -6dB. For the experimental results given here diodes of type HSMS-2822 and power divider of type LRPS-2-11 were used.

The mixer output lower sideband signal is

$2f_{LO}-f_{RF}-\phi+90°$ and
$2f_{LO}-f_{RF}-\phi+450°$

These signals add in phase and have the desired phase conjugate response. When $f_{LO}=f_{RF}$, the IF signal is at f_{RF} therefore the inherent RF-IF isolation of the circuit must be improved.

To demonstrate that the approach of using a balanced sub-harmonic mixer works as the phase conjugate element in a retrodirective array, a two-element array was constructed and its response is shown in Figure 15. Here f_{LO} = 990MHz and f_{RF} = 1.0GHz. The retrodirective array thus constructed has a much broader azimuthal response than its passive counterpart indicating that the technique does actually function correctly.

The RF-IF isolation at the output port of the sub-harmonic mixer can be improved by cascading two sub-harmonic mixers together as shown schematically in Figure 16. Here the RF signals to the two harmonic mixers are made to be 180° out of phase, whereas a phase difference of 90° is applied to the LO signal fed to the two mixers. This arrangement results in self-cancellation of the RF signal.

The operation of cascaded sub-harmonic mixer can be understood with the help of Figure 16.

As before let the LO signal be f_{LO} and RF signal be $f_{RF}+\phi$ where ϕ is the phase term to be conjugated.

MIXER 1

Then the LO and RF signal to mixer 1 in Figure 16 will be f_{LO} and $f_{RF}+\phi$

Using the notation in Figure 15 the signals at port 3 (mixer M1)

LO $f_{LO}+90°$

RF $f_{RF}+\phi+90°$

RF $f_{RF}+\phi+270°$

output of mixer M1

sum product

$2(f_{LO}+180°)+(f_{RF}+\phi+270°)=f_H+\phi+630° \Rightarrow f_H+\phi+270°$

difference product

$2(f_{LO}+180°)-(f_{RF}+\phi+270°) \Rightarrow f_L-\phi+90°$

Output of mixer M2

sum product

$2(f_{LO}+360°)+(f_{RF}+\phi+270°)=f_H+\phi+990° \Rightarrow f_H+\phi+270°$

difference product

$2(f_{LO}+360°)-(f_{RF}+\phi+270°) = f_L+\phi+450° \Rightarrow f_L-\phi+90°$

As before the difference outputs from M3 and M4 ie (10) and (11) add in phase. Therefore the output from mixer 2 will be

$f_L-\phi+90°$

Finally the IF outputs from mixer 1 and 2 add in phase to give maximum signal strength for the conjugated IF signals at the output port. Here the difference product (f_L) bears the phase conjugate relationship with the incident RF signal. The sum product from the mixers (f_H) which does not contain a phase conjugate component is filtered out. The LO signal are self cancelled at mixer 1,2 outputs. The RF signals from mixer 1 is $f_{RF}+\phi+90°$ and, from mixer 2 is $f_{RF}+\phi+270°$,

therefore the RF signal is cancelled.

The isolation performance of the cascaded sub-harmonic mixer was simulated with an operating frequency 1GHz. Simulated results using lossy microstrip interconnects constructed on FR4 substrate show the LO isolation is -61dB and the RF isolation is -44dB.

The invention thus provides an improved retroreceive antenna system, and also a novel method and apparatus for phase conjugation. Preferably, these two aspects of the invention are used together, but each may be used separately.

CLAIMS

1. A method of deriving phase conjugate information from an input signal of a given frequency, the method comprising mixing the incoming signal in a harmonic mixer with a local oscillator signal, and in which the local oscillator signal is of said given frequency and is substantially stronger than said input signal.

2. A circuit arrangement for deriving phase conjugate information from an input signal of a given frequency, comprising a harmonic mixer having a first input receiving said input signal and a second input for connection to a local oscillator, the circuit arrangement further comprising a local oscillator operating at said frequency and connected to supply said second input with a signal which is substantially stronger than said input signal.

3. A circuit arrangement according to claim 2, in which the harmonic mixer comprises an antiparallel diode pair in combination with a combiner/coupler and a filter.

4. A circuit arrangement according to claim 3, in which the diode pair is connected in shunt with the combiner/coupler and the filter.

5. A circuit arrangement according to claim 3, in which the diode pair is connected in series with the combiner/coupler and the filter.

6. A circuit arrangement according to claim 2, in

which the harmonic mixer comprises a 180 degree hybrid rat-race having a SUM port, a DIFFERENCE port, and a pair of arms connecting to a summer, each of the arms containing an antiparallel diode pair, and the output being taken from the summer output.

7. A retroreceive antenna system comprising an antenna array having two elements spaced apart, means for deriving from the signals received at the two elements the phase relationship between said received signals, and means for steering the antenna array to minimise the phase difference; and in which said means for deriving the phase relationship comprises a mixer.

8. A system according to claim 7, in which the mixer is connected to mix the signal received by one antenna element with a signal produced by a local oscillator.

9. A system according to claim 8, in which the local oscillator operates at twice the frequency of the incoming signal.

10. A system according to claim 9, in which the local oscillator is controlled by a signal received from a reference antenna element positioned at the centre of the antenna array.

11. A system according to claim 7, in which the mixer is a harmonic mixer forming part of a circuit arrangement in accordance with any of claims 2 to 6.

12. A method of deriving phase conjugate information

from an input signal of a given frequency, substantially as hereinbefore described with reference to the drawings.

13. A circuit arrangement for deriving phase conjugate information from an input signal of a given frequency, substantially as hereinbefore described with reference to the drawings.

14. A retroreceive antenna system substantially as hereinbefore described with reference to the drawings.

Application No: GB 9904179.0
Claims searched: 1-6, 12, 13

Examiner: Mr.Sat Satkurunath
Date of search: 30 June 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): H3R: RMX

Int Cl (Ed.6): H01Q, H03D

Other: Online: WPI, JAPIO, EPODOC

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	US 5113094	GRACE - see especially figure 3 and abstract	1, 2
X	US 4723113	MARCOUX - see especially figure 2	1, 2
X	US 3983489	GITTINGER - see especially figure 3 and abstract	1, 2

X Document indicating lack of novelty or inventive step	A Document indicating technological background and/or state of the art.
Y Document indicating lack of inventive step if combined with one or more other documents of same category.	P Document published on or after the declared priority date but before the filing date of this invention.
	E Patent document published on or after, but with priority date earlier than, the filing date of this application.
& Member of the same patent family	